THE SCIENTIFIC MONTHLY

NOVEMBER, 1916

EXPLOSION CRATERS

By N. H. DARTON

U. S. GEOLOGICAL SURVEY[1]

ALTHOUGH most great craters are on top of volcanic peaks, a few big holes of volcanic origin are on plains and not connected with lava outflows. These are rimmed by a ridge of fragmental material evidently blown out of the hole, so that they are clearly the results of an explosion. One crater of this character, however, Crater Mound (formerly Coon Butte) in Arizona, is believed by some observers to have been caused by impact of a meteor. As there is no direct evidence as to the origin of this great hole and its rim of fragmental ejecta, it may be interesting to present for comparison facts regarding some craters which are closely similar in all essential respects.

Among long-known holes ascribed to volcanic explosion and not connected with lava outbursts are the "maars" in the Rhine valley and the craters of Eiffel, Auverne, Montecchio, Albani, Nemi, Astromi, Faifa, etc., of Nassibe, in Madagascar and at Lonar, India. The latter, as described by Dr. Blandford, is a hole about a mile in diameter, 300 to 400 feet deep, in a great lava plain. Except on the north and northeast sides, there is a rim 40 to 100 feet high composed of loose blocks of basalt similar to the rocks on the sides of the hole. The latter are bent up very slightly. As to the competency of volcanic explosion to cause a crater, many illustrations have been observed, notably in the great Bandai-San eruption[2] in Japan in 1888, which made a vast crater in a mountain where there had been no activity for many centuries. There was no lava effusion connected with this outburst. The eruption of Krakatoa in 1883 is another impressive instance.

In the course of the present European war many a huge "crater" or "entonnoir" has resulted from the explosion of "mines" intended to destroy fortifications or dislodge troops, and it is interesting to have an example of this kind to compare with some natural craters. One

[1] Published by permission of the Director.

[2] "The Eruption of Bandai-San," Seis. Soc. Japan, Vol. 12, pp. 139–222, 1890.

large "entonnoir" on the Franco-German line of struggle is shown on Page 429. Judging from some details of remains of passageways shown in the foreground, its diameter is about 150 feet and depth 50 feet. It was produced by the explosion of several tons of some powerful explosive placed in a chamber at the end of a long tunnel 50 to 60 feet below the surface. The end of the tunnel next the chamber was securely blocked before exploding the mine in order to have the utmost

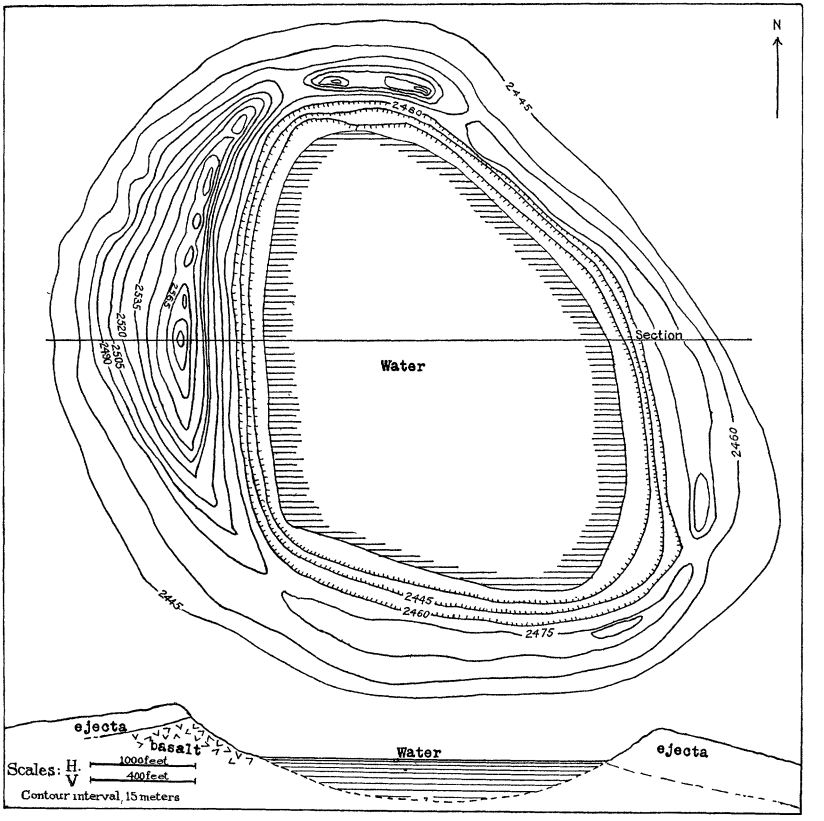

FIG. 1. CONTOUR MAP AND CROSS SECTION OF THE CRATER OF ALCHICHICA IN PUEBLA, MEXICO, AFTER ORDONEZ.

effect of upheaval. The material apparently is compact earth and probably the uplifted material was torn out without much upbending of the sides from which it is detached.

Several years ago Ordoñez described some remarkable craters in Mexico which afford some very interesting facts for comparison. One group is on the plateau near Orizaba Peak in Puebla; the other group is in Valle Santiago. Ordoñez regards them as the result of explosions marking the last phase of volcanic activity in the region. The cause was igneous action at no great depth and the locus of explosion was determined by some superficial influence.

The craters of the Puebla[3] region are in two principal groups. One group of four is in the vicinity of the Hacienda and Sierra of Techachalco, about 25 miles north-northwest of Orizaba Peak and not far southwest of Limon Station on the Interoceanic Railroad. The other group is near Alxoxuca, a small settlement eighteen miles northwest of Orizaba Peak. The configuration and structure of two of the principal members of the first group are shown in Figs. 1 and 2, copied

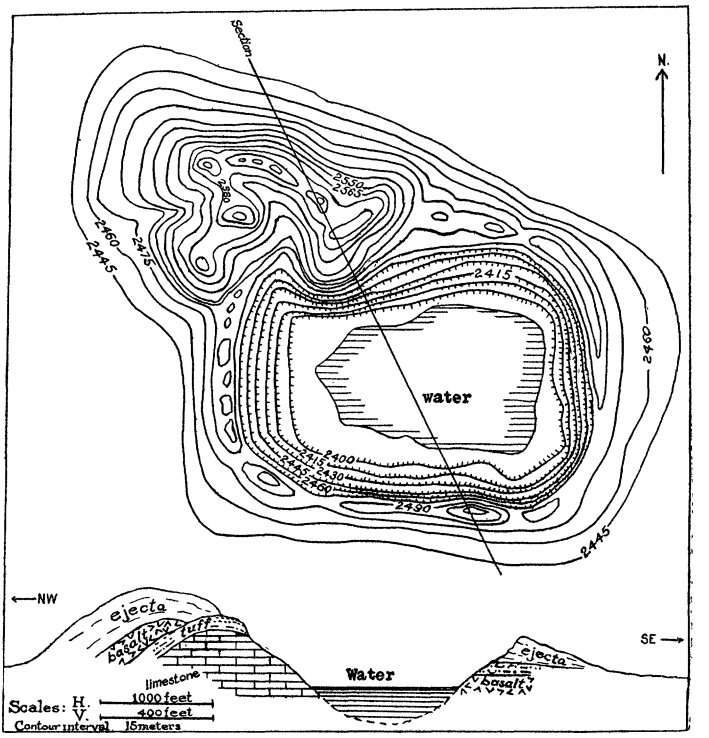

FIG. 2. CONTOUR MAP AND CROSS SECTION OF THE CRATER OF ATEXCAQUI IN PUEBLA, MEXICO, AFTER ORDONEZ.

from Ordoñez's memoir. The largest crater, known as Alchichica, is circular, contains a large shallow lake, and has a diameter of slightly more than a mile. The water level is about 50 feet below the surrounding plain. On the east and south sides the encircling ridge is low, but on the west it rises 325 feet. The inner slopes are steep, the outer ones more gradual. Both walls consist of ash, lapilli and pumice, evidently ejected from the crater, but on the west side these are seen to lie on a mound of basalt of some old flow. Fragments of basalt and of slates, limestones and other materials are included in the mass of

[3] "Los Xalapazcos del Estado de Puebla," Inst. Geol. de Mexico, Parergones, Vol. 1, No. 9, 1905.

ejecta constituting the encircling ridge. There is no evidence of disturbance of the beds.

Atexcaqui, six miles southwest of Alchichica, has an elliptical crater about three fifths of a mile wide from east to west and two fifths of a mile wide from north to south. Some of its features are shown in Fig. 2. The surface of the lake occupying the crater is about 90 feet below the adjoining plain. The encircling ridge is from 200 to 250 feet above the lake, but on the northwest side its height increases to about 600 feet on account of the presence of a mound of horizontal Cretaceous strata on which the ejecta is piled. On the other sides are low walls of basalt, capped by nearly horizontal beds of yellow, andesitic tuff which constitutes the surface of the adjoining plains. The material ejected from the hole and constituting the encircling ridge is piled up on this tuff to a thickness of 40 to 60 feet. The inner slopes of the crater are steep at most places. The ejecta of the encircling ridge is in irregular sheets sloping outward at a low angle. The principal materials are those which underlie the plain: ash, cinders, tuff, and numerous fragments of the basalt. There is also a small proportion of limestone, granite, diorite and andesite, such as probably underlie the locality at considerable depth. The limestone is of the same sort as that which constitutes the hill on the northwest side of the crater. The explosion has blown a round hole through the basalt, limestone and overlying tuff, but has not disturbed the remaining edges. The volume of ejected material is not estimated, but it must be great and apparently sufficient to fill the hole.

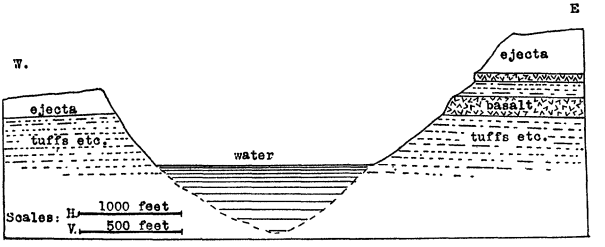

FIG. 3. SECTION ACROSS THE EXPLOSION CRATER OF ALXOXUCA IN PUEBLA, MEXICO, AFTER ORDONEZ.

La Preciosa, a smaller crater with lower surrounding ridge, also contains a lake said to be 275 feet deep. Its rim consists of a mass of ejected material somewhat irregularly distributed. The hole is in the tuff of the plain. Quecholac, which lies out on the plain some distance from the others, is about three fifths of a mile in diameter, with low encircling ridge 80 to 160 feet high. This ridge consists of ejecta, mainly cinders, lapilli and pumice, and a few rocks of the older formations in irregular sheets dipping gently outward. The underlying strata are not exposed. The lake is 300 feet deep.

The craters about Alxoxuca are on the plain at the foot of a volcanic ridge, but the materials in the walls and slopes are entirely of the tuffs which make up the plain. The craters are close to cones from which lava flowed recently, at one place overlapping the ejecta from the explosion craters. The principal crater, known as Alxoxuca, is somewhat more than a half mile in diameter, and the lake which it contains is 200 feet deep. The cross section, Fig. 3, shows the principal features on a west to east line. Two lava sheets are intercalated in the tuff on the east side, which rises considerably higher than the west side. The encircling rim consists, as in other craters, of fine ejecta containing many basalt fragments. The deep large crater of Tecuitlapa contains, as shown in Fig. 4, a conical mass of basalt and

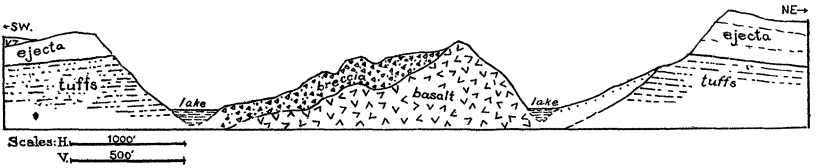

FIG. 4. SECTION ACROSS THE EXPLOSION CRATER OF TECUITLAPA IN PUEBLA, MEXICO, AFTER ORDONEZ.

breccia with three small craters, a feature very similar to Zuñi Lake in New Mexico. Steep walls rise from the central lake to the crest of the encircling ridge of ejecta which is 300 feet high and slopes gently to the adjoining plain. The interior cone and its craters are clearly of more recent age than the large crater and undoubtedly represent a final stage of the volcanic activity.

Two other craters, five miles east of Alxoxuca, are known as Xalapazco Grande and Xalapazco Chico. They contain no water. As shown in Fig. 5, they are less than a half mile in diameter, but the

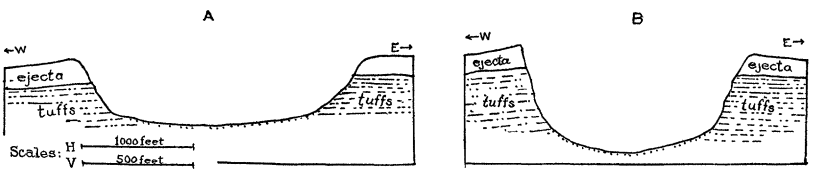

FIG. 5. *A.* SECTION ACROSS THE CRATER, AXALAPAZCO GRANDE. *B.* SECTION ACROSS THE CRATER, AXALAPAZCO CHICO, PUEBLA, MEXICO, AFTER ORDONEZ.

encircling rim does not rise high above the plain. The larger crater is 220 feet deep, and the smaller one nearly 400 feet. As in the case of the others, they are blown out through andesitic tuffs constituting the general valley floor and the rims consist of a large volume of fine ejecta containing much basaltic material. Ordoñez suggests that at the time of eruption a large volume of water was ejected with the

fine materal which would account for the irregular bedding in the ejecta in the encircling ridges.

Other explosion craters in south central Mexico have been described by Ordoñez, notably the fine group of eleven in the Valle de Santiago[4] and the crater at Xico,[5] near Mexico. These craters are in a plain underlain by tuffs and the beds adjoining the holes are not disturbed. The craters are surrounded by ridges of ejecta and all are the products of a similar cause, but in some cases two or more stages of development are apparent. The largest is more than a mile in diameter.

An explosion crater at Tacámbaro, in Michoacán, has been described by Rubio.[6] It contains a lake nearly a half mile in diameter, and the surrounding ridge of ejecta is more than 500 feet high on one side. The walls are basalt and the ejecta are ash, lapilli and tuff, with rock fragments.

Hornaday[7] and Lumholtz[8] have described a group of remarkable explosion craters in the northern part of Sonora, Mexico, fifteen to

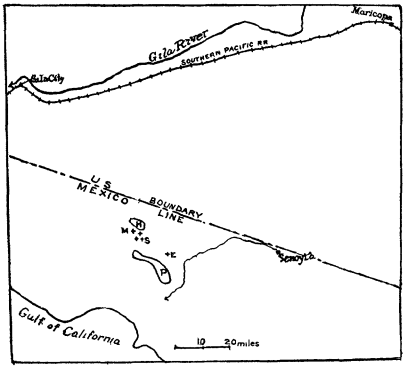

FIG. 6. MAP OF PART OF SONORA DESERT IN MEXICO AND ARIZONA, showing location of craters near Pinacate Mountains, after G. Sykes. *P*, Pinacate Mountains; *H*, Hornaday Mountains; +, craters; *S*, Sykes Crater; *M*, MacDougal Crater; *E*, Crater Elegante.

twenty-five miles south of the International Boundary line, about 100 miles southeast of Yuma, Arizona. This area is shown in the following map:

[4] "Les volcans du valle de Santiago," por E. Ordoñez, Soc. Antonio Alzate Mems., Vol. 14, pp. 299–326, pls. IV.–IX., 1897. Also "Les Crateres d'explosion de Valle de Santiago," por E. Ordoñez, Guide des Excursions Xe Cong. Geol. Int., Mexico, 1906, XIV., Excursion du Nord, 9 pages, plate.

[5] "Los crateros de Xico," *Bol. Soc. Geol. Mexicana*, Tomo 1, pp. 19–24, 1905.

[6] "El Axalapazco de Tacámbaro," por P. O. Rubio, *Bol. Soc. Geol. Mexicana*, Tomo 2, pp. 65–69, 1906.

[7] "Camp Fires on Desert and Lava," by W. T. Hornaday, Scribner's, 1908.

[8] "New Trails in Mexico," by Carl Lumholtz, Scribner's, 1912.

One of these craters in the plain 2½ miles northeast of Tinaja de los Papagos was named Sykes Crater by Hornaday. According to Lumholtz it had been visited by Sr. Y. Bonillas of Nogales in 1882. Sykes, who was geographer of Hornaday's expedition, found that the depth of the crater is 750 feet, its diameter at bottom 1,400 feet, and the bottom is 150 feet above sea level. A view of this great hole is given in Fig. 7. Lumholtz states that the rim is 130 feet high where

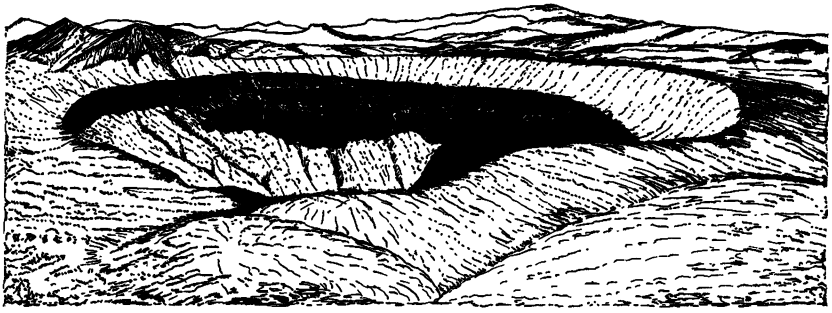

FIG. 7. SYKES CRATER, IN SONORA, MEXICO. Looking southeast. Pinacate Mountains in distance. After a colored view by Hornaday.

he crossed it. It evidently consists of ejecta and Hornaday states that in places the apex of the rim is "sandstone formed by the fusing of masses of volcanic sand under the influence of intense heat" and regards the material as having been thrown out of the crater.

Another great crater in the same vicinity has been named MacDougal Crater by Hornaday. It is in the lava plain a short distance southwest of the foot of Hornaday Mountains. A view of this hole, from a photograph kindly supplied by Mr. Charles Sheldon, is given in Fig. 8. The diameter of the bottom is 3,600 feet and depth below

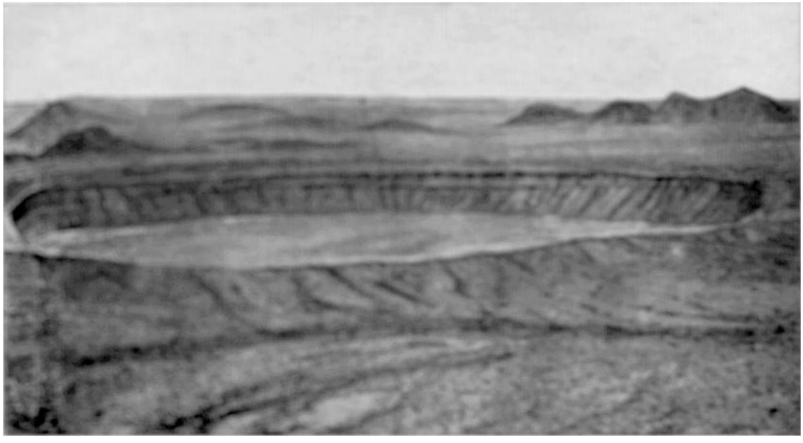

FIG. 8. MACDOUGAL CRATER, LOOKING SOUTHWEST FROM TOP OF HORNADAY MOUNTAINS, SONORA, MEXICO. Photo by C. Sheldon, 1916.

rim 400 feet. Its bottom is about 50 feet above sea level. The walls are mostly very steep and there is the usual surrounding rim of ejecta.

Lumholtz found a fine large circular crater in the lava plain a short distance northeast of Sierra del Pinacate, to which he has given the name Crater Elegante. It is six miles northeast of the central peak, near the edge of a plain covered by a thin lava sheet. He estimates its depth at 800 feet and a rough measurement gave a mile

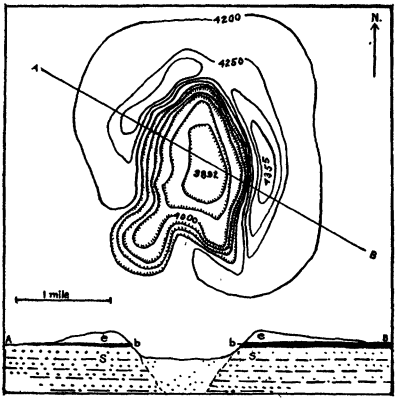

FIG. 9. CONTOUR MAP AND CROSS SECTION OF KILBURN CRATER, NEW MEXICO. Contour interval 50 feet, datum sea level. *s*, stratified sand; *b*, basalt; *e*, ejecta.

diameter. It is rimmed by a ridge rising about 150 feet above the surface of the plain. The bottom is flat and talus rises about half way up the sides. The view given by Lumholtz shows alternations of regularly bedded material.

The Afton craters in southern New Mexico, thirty miles north-

FIG. 10. LOOKING NORTHEAST INTO KILBURN CRATER NEAR AFTON, in southern New Mexico. The black streak is a thin sheet of lava much older than the hole. Note ranch to right of center of view. Photographed by W. T. Lee.

west of El Paso, described by Lee,[9] are closely similar to the craters in Mexico described above. They are in a level plain of thick stratified river deposits capped by a thin sheet of late basalt. One is a mile in diameter and about 150 feet deep; the other, two miles north, is two miles long and about 250 feet deep. Both are circled by rims of ejecta rising 10 to 200 feet above the plain. The inner slopes are steep and the outer slopes gentle. The ejecta, which lies on a fifteen-foot sheet of basalt, consists of sand, cinders, pumice, and blocks of basalt, and in part, especially near the base, shows irregular bedding with low outward slope. All came from below and was thrown out by an explosion, but the volume is much less than that of the craters. The configuration and structure of the larger crater is shown in Fig. 9. A view is given in Fig. 10.

Lee suggests that the explosion was caused by formation of steam generated by lava forced into the water-saturated sands.

The crater holding Zuñi Salt Lake is in the central-western part of New Mexico, about 75 miles south of Gallup. When I published a description of this feature in 1905,[10] I was inclined to believe that it was due partly to volcanic action and partly to subsidence caused by removal of underlying salt beds by solution. After comparing it with the conditions in other regions, I feel convinced it is an explosion crater. Some of the features are shown in Figs. 11 and 12. It is

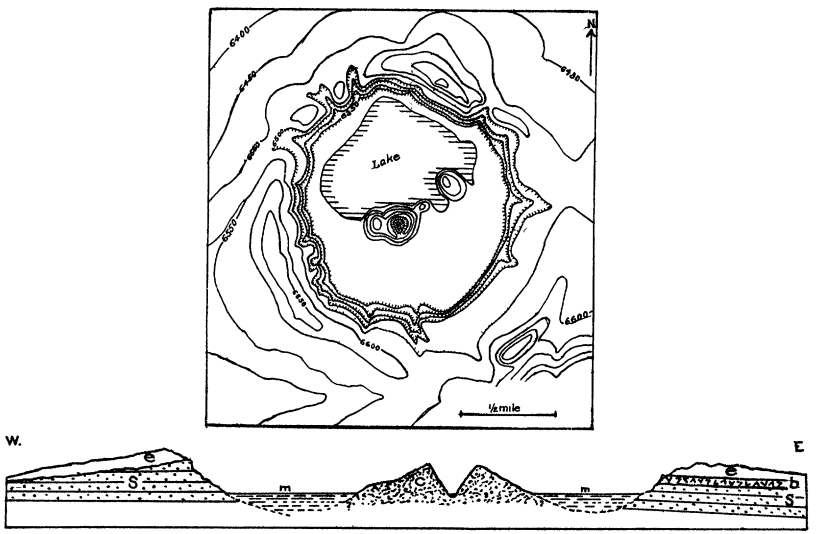

FIG. 11. CONTOUR MAP AND CROSS SECTION OF ZUÑI SALT LAKE IN WEST CENTRAL NEW MEXICO. *e*, ejecta; *s*, cretaceous sandstone; *c*, cinder cone; *m*, mud and salt recently deposited by the lake.

[9] "Afton Craters of Southwestern New Mexico," by W. T. Lee, *Bull. Geol. Soc. Am.*, Vol. 18, pp. 211–220, pls. 3–4, 1907.

[10] "The Zuñi Salt Lake," by N. H. Darton, *Jour. Geol.*, Vol. 13, pp. 185–193, 1905.

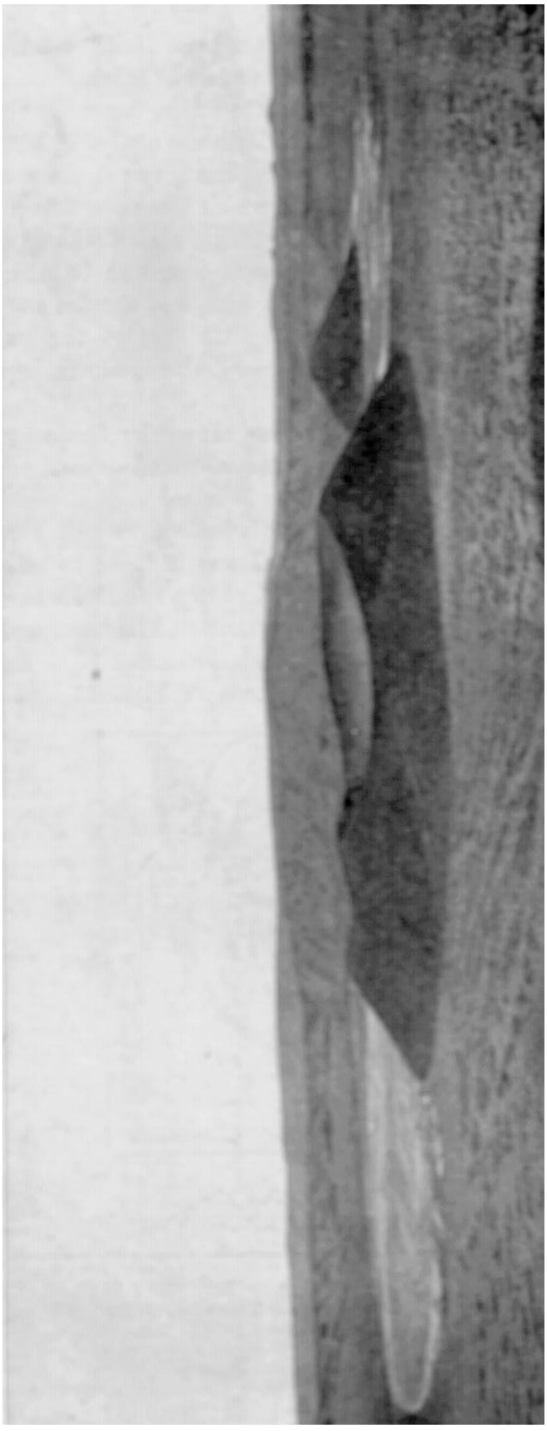

FIG. 12. LOOKING NORTH ACROSS THE CRATER HOLDING ZUNI SALT LAKE, NEW MEXICO. Large cinder cone with crater is in center; walls and plateau of Cretaceous sandstone surmounted by encircling ridge of ejecta, in mid-distance.

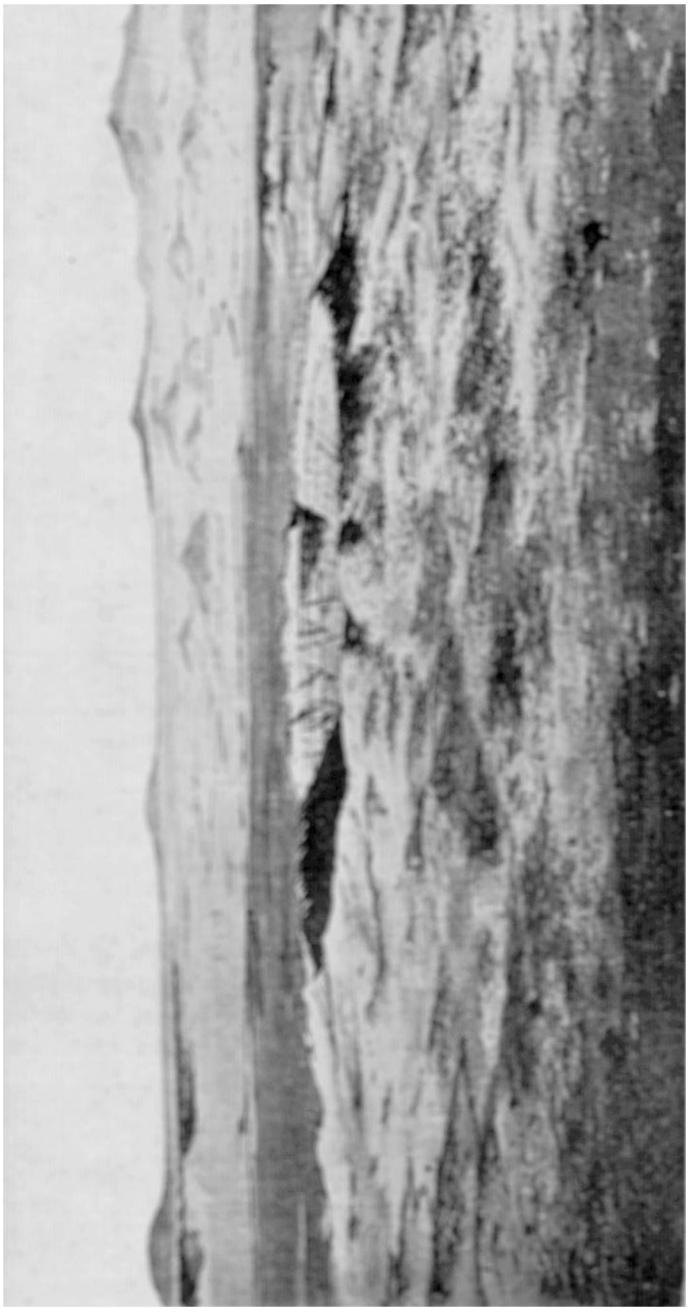

FIG. 13. BIRD'S-EYE VIEW OF CRATER MOUND, ARIZONA. Looking northwest San Francisco Mountains in the distance to the right.

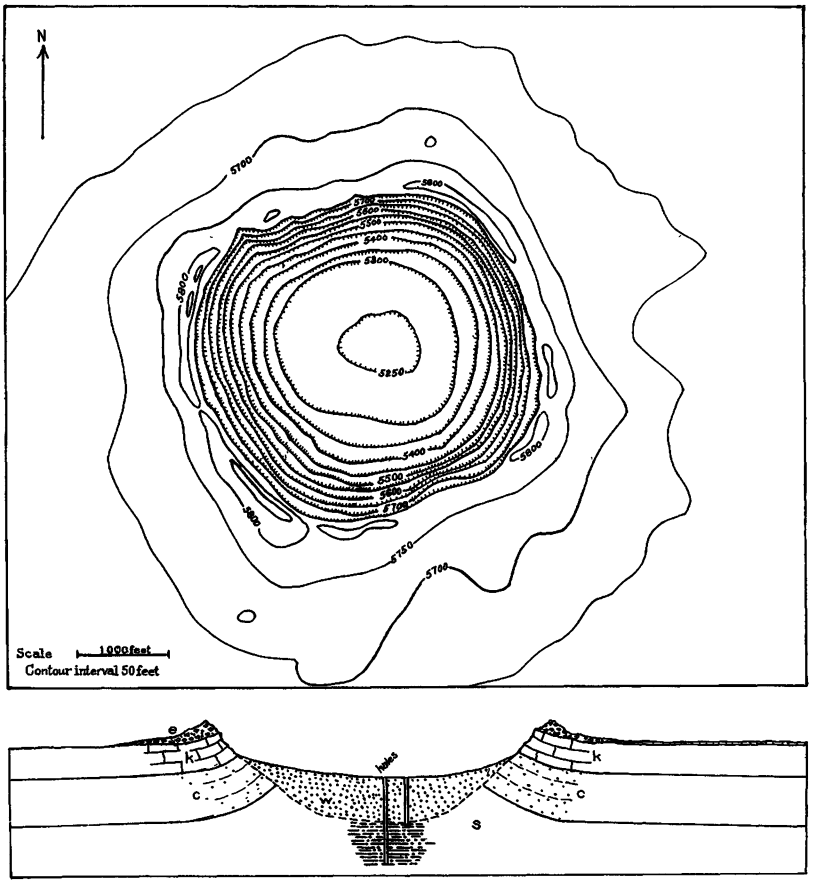

FIG. 14. CONTOUR MAP AND CROSS SECTION OF CRATER MOUND, ARIZONA. *e*, ejecta; *K*, Kaibab limestone; *C*, Coconino sandstone; *S*, Supai red sandstone; *w*, sand, etc.

about a mile in diameter, 150 feet deep, and encircled by a wide rim of ejecta consisting mainly of fine scoria containing fragments of the sedimentary rocks which underlie the region. Part of the material is stratified and cross bedded. The walls of the crater are Cretaceous

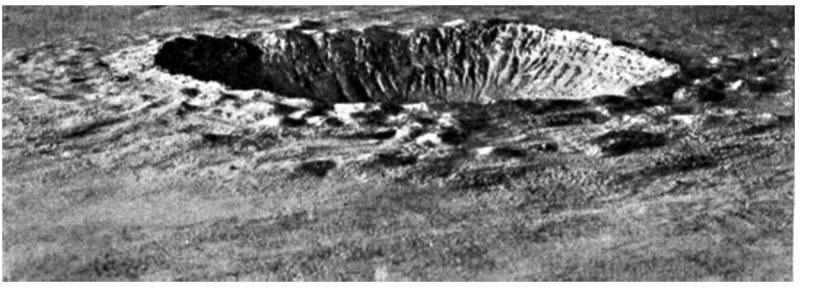

FIG. 15. A MODEL OF CRATER MOUND, ARIZONA. Constructed for G. K. Gilbert from a detailed topographic map by Marcus Baker.

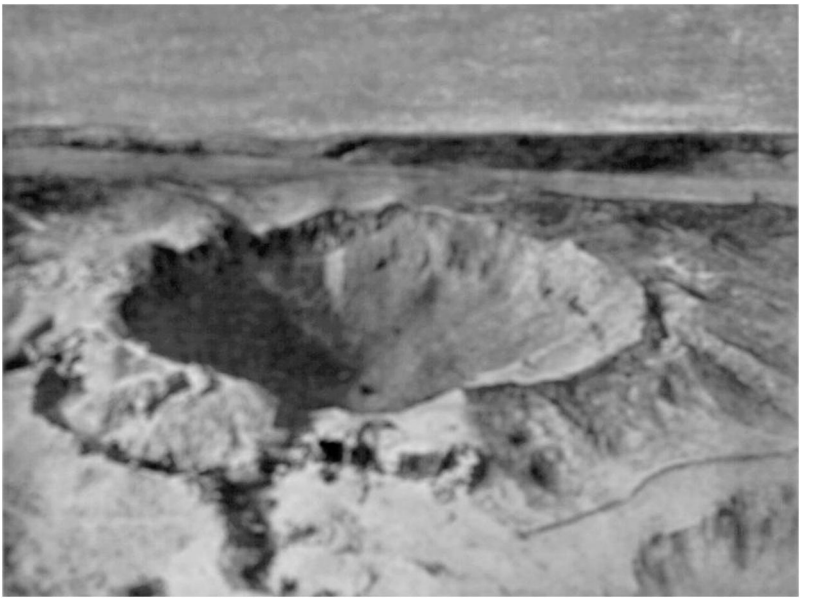

FIG. 16. CRATER REMARKABLY LIKE CRATER MOUND IN APPEARANCE, caused by explosion of a "Mine" in the trenches in northern France in 1915.

sandstone, in part capped by a lava sheet of moderate antiquity. From the lake occupying part of the center of the crater rise two small cones of scoria, one with deep crater, and evidently very recent. The ejected material covers a wide area on the rim and beyond, and while it is much too small in volume to fill the crater, probably a large amount has been

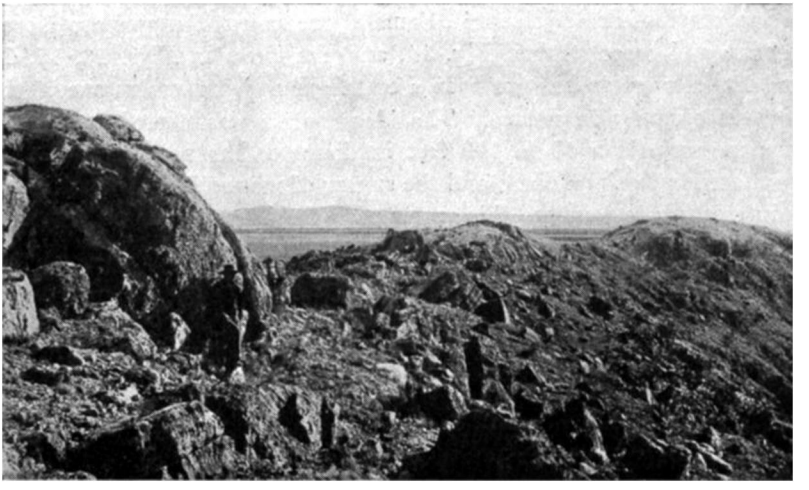

FIG. 17. PART OF THE GREAT RIM OF FRAGMENTS OF LIMESTONE AND SANDSTONE EJECTED FROM CRATER MOUND, ARIZONA. Photo by G. K. Gilbert. Many of the masses weigh more than 5,000 tons, the largest 20,000 tons and the total amount of ejecta is about 250 million tons or approximately sufficient to fill the hole.

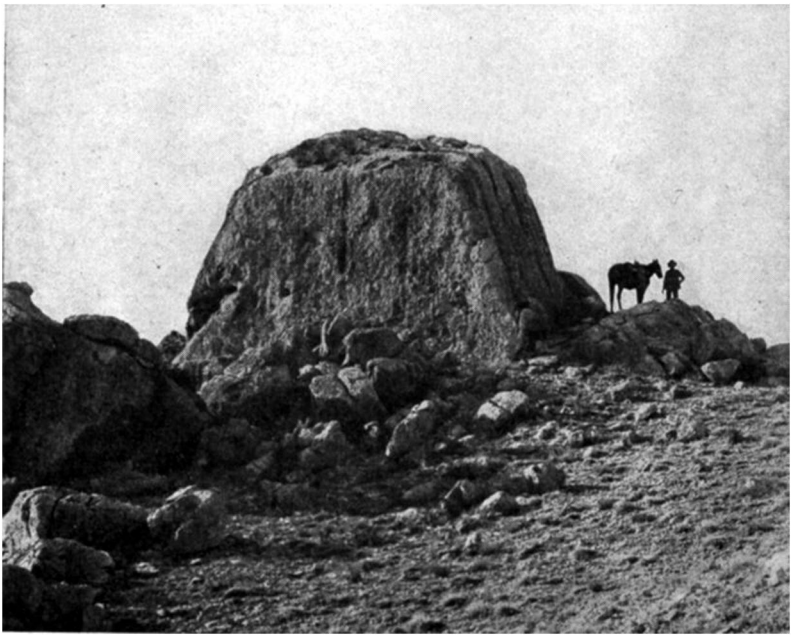

FIG. 18. LARGEST BLOCK IN THE EJECTA ON RIM OF CRATER MOUND, ARIZONA. A mass of limestone 60 feet in diameter weighing about 20,000 tons. Photo by G. K. Gilbert.

removed by erosion. Undoubtedly its bedded condition was caused by a simultaneous outburst of water.

Crater Mound, or Coon Butte as it was originally named, is so well known that I will not review it in detail and there is nothing new to add to previous descriptions.[11] Some of the salient features are shown in map and cross section, Fig. 14, and the views in Figs. 13, 15, 17 and 18. Its origin has not been ascertained and it remains one of the greatest enigmas in nature. The idea that it was caused by impact of a meteoric iron 50 to 100 feet in diameter has not yet been substantiated by borings, shaft and the survey of magnetic declination. It is interesting to compare this crater with the illustrations of explosion craters given above and the close similarity of many features is very suggestive in connection with Gilbert's original suggestion that Crater Mound was caused by a steam explosion.

[11] Gilbert, G. K., "The Origin of Hypotheses Illustrated by the Discussion of a Topographic Problem," Geol. Soc. Wash., Presidential Address, 1895, and *Science*, N. S., Vol. 3, pp. 1–12, 1896. Barringer, D. M., and Tighlman, B. C., "Coon Mountain and Its Crater," *Phil. Acad. Sci., Proc.*, 1906, pp. 861–914. Merrill, G. B., "The Meteor Crater of Canyon Diablo, Arizona. Its History, Origin and Associated Meteoric Irons," *Smith. Miscell. Coll.*, Vol. 50, Pt. 4, pp. 461–498, 1908. Barringer, D. M., "Meteor Crater in Northern Central Arizona," *Nat. Acad. Sci.*, Nov. 16, 1909, 24 pp., pls. Darton, N. H., "A Reconnaissance of Parts of Northwestern New Mexico and Northern Arizona," U. S. Geol. Survey, Bull. 435, 1910.